03 Jun 1993, 10:30 am - 12:30 pm

Analysis of Fatal Accidents Caused by Trench Failure

Yasuo Toyosawa
Research Institute of Industrial Safety, Ministry of Labour, Japan

Noriyuki Horii
Research Institute of Industrial Safety, Ministry of Labour, Japan

Satoshi Tamate
Research Institute of Industrial Safety, Ministry of Labour, Japan

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 5.22

Analysis of Fatal Accidents Caused by Trench Failure

Yasuo Toyosawa and Noriyuki Horii
Senior Research Officers, Research Institute of Industrial Safety, Ministry of Labour, Japan

Satoshi Tamate
Research Officer, Research Institute of Industrial Safety, Ministry of Labour, Japan

SYNOPSIS The purpose of this paper is to clarify the failure mechanism and how workers died due to trench failures with close examination of the situations surrounding these accidents. We carried out a statistical analysis of various factors obtained from fatal accident data which were reported by the Labour Standard Office to the Ministry of Labour. This examination revealed some important characteristics of fatal accidents due to trench failures.

NTRODUCTION

It is well known that accidents caused due to trench ailure have frequently occurred at construction sites. he need of decreasing these accidents is of major nportance in Japan.

For the purpose of establishing countermeasures for he prevention of accidents in various stages. It is ecessary to understand the basic information about fatal ccidents due to earth failure. Little attention has been iven to the occupational fatal accidents due to earth ailure, especially on the relations between the failure atterns and cause of death. We have examined 90 fatal ccidents which occurred during the 1986 ~ 1988 period in apan. In this report, we are concerned with clarifying the ailure mechanism and how the workers died due to these ccidents with close examination of the situations rrounding these accidents.

GENERAL ASPECTS OF FATAL ACCIDENTS BY EARTH FAILURE JAPAN

First of all, we would like to show the general pects of fatal accidents due to earth failure in Japan. ble 1 shows the number of accidents that have occurred cently. According to this table, between 50 and 100 rkers are killed by earth failure every year. This figure so includes workers killed by falling rocks. Table 2 ows the number of fatal accidents of each type of nstruction work and the type of slope failure. The numbers in this table are an accumulation of data from the years 1985 to 1991.

32% of fatal accidents occurred during the carrying out of waterworks (water supply and sewerage) and 20% during road works. Almost all of the accidents during the waterworks happened in trenches. For road works, Sabo works (sediment control works) and land development works happened at cutting slope sites.

2 ANALYSIS OF FATAL ACCIDENTS DUE TO EARTH FAILURE

For this report, we carried out a statistical analysis of various factors obtained from accidents data between 1986 and 1988 which were reported by an inspection officer of the Labour Standard Office to the Ministry of Labour. When the data was found to be insufficient, we contacted the inspecting officer directly who inspected the accidents to certify the facts.

Every accident was examined using the following items. Table 3 shows the code for analysis.

2-1 Cause of death and injury part

The cause of death written down in the reports depended on the death certificate (in every fatal accident, the worker who died had been diagnosed by the doctor). The injury leading to the workers death was also written in the report. We classified according to these description. For example, for "fracture of skull" or "suffocation due to pressure on chest", we categorized as "fracture" or "suffocation" and part injured as the "head"

Table 1 Number of accidents in construction works(1981~1991) (UNIT:NUMBER OF PERSON)

TYPE OF ACCIDENTS \ YEAR	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
TOTAL	1,173	1,113	1,106	1,083	960	927	983	1,106	1,017	1,075	1,047
SLOPE FAILURE	97 (8.3%)	82 (7.4%)	68 (6.1%)	84 (7.8%)	62 (6.5%)	58 (6.3%)	80 (8.1%)	69 (6.2%)	56 (5.5%)	76 (7.1%)	75 (7.2%)

Table 2 A number of fatal accidents at construction works(1981~1991)

TYPE OF CONSTRUCTION WORK / TYPE OF ACCIDENT		CIVIL ENGINEERING WORKS														BUILDING WORKS						EQUIPMENT WORKS					ELSE	TOTAL
		DAMS	TUNNELS	SUBWAYS	RAIL WAYS	BRIDGES	ROADS	RIVER WORKS	SABO SEDIMENT CONTROL	LAND DEVELOPMENT	WATER WORKS	PORTS	OTHERS	TOTAL	BUILDING	WOODEN BUILDING	MECHANICAL WORKS FOR BUILDING	OTHERS	TOTAL	ELECTRICAL WORKS	MECHANICAL WORKS	OTHERS	TOTAL			
SLOPE FAILURE	FAILURE OF EARTH	4	5	0	3	5	86	22	36	40	173	0	51	425	18	4	3	4	29	1	0	8	9	2	465
	FAILURE OF ROCKS	2	5	0	0	0	6	1	3	1	1	0	2	21	0	0	0	0	0	0	0	0	0	0	21
	ROCK FALL	1	3	0	0	1	16	6	20	2	3	1	8	61	1	0	0	0	1	0	0	0	0	0	62
	TOTAL	7	13	0	3	6	108	29	59	43	177	1	61	507	19	4	3	4	30	1	0	8	9	2	548

or "chest". When there was no specification about part injured in the reports, such as "death by suffocation" or "death by pressure", we categorized them into "whole body and unspecified".

2-2 Buried portion

We tried to classify into 5th group what part of the body was buried (buried portion) when failure occurred.

2-3 Failure pattern (classification of failure)

The categories of failure patterns are described in Section 3-2 below.

2-4 Cause of failure

There are a lot of factors causing a failure.

In this report, we have focused on the existence of back-fill. Category 1 included a situation in which a part of the slip surface consisted of back-fill .

2-5 Size and gradient of trench or slope

Depth and gradient of the trench were surveyed.

2-6 Amount of failure

Volume of failure soil were surveyed. It could explain the degree of collapse.

2-7 Classification of works

The kinds of work that the worker who died did when rench failure occurred was classified.

8 Retaining (earth support) structure

The situations of installing earth support structure ere classified.

Table 3 Code for analysis

Cause of death	Injured body part
1. Suffocation by pressure 2. Suffocation (the cause was unspecified) 3. Shock 4. Rupture of internal organs (Internal injury) 5. Fracture 6. Pressure 7. Injury (intracranial injury, etc.) 8. Others and unspecified effects	1. Whole body and unspecified 2. Head 3. Neck 4. Chest 5. Abdomen and pelvis 6. Leg 7. Compound 8. Others or unknown

Buried portion	Cause of failure (existence of back-fill)
1. Entire body (worker buried entirely) 2. Below neck (worker buried below neck) 3. Below chest or abdomen (worker buried below chest or abdomen) 4. Others (hit by collapsed soil-mass or a part of the body was between collapsed soil and trench wall, etc.) 5. Unknown	1. Existence of back-fill 2. Natural ground 3. Others 4. Unknown

Classification of works	Situations of installing earth support
1. Readjustment of excavated trench bottom 2. Trimming of trench wall 3. On setting of trench support 4. Pipe setting 5. Other works concerning pipe setting 6. Inspection, investigation and measuring 7. Others 8. Unknown	1. Already installed 2. During installing or dismantling 3. Before installation (Installation was planned) 4. No installation (Installation was not planned) 5. Unknown

FEATURES OF FATAL ACCIDENTS BY TRENCH FAILURES

-1 Cause of death

Generally speaking, we are apt to think that the workers are killed by earth failure caused by suffocation in collapsed soil. It is worthwhile to examine the subjects more closely. To consider the cause of death, we checked the diagnosis (cause of death and part injured), buried portion and the depth of trench.

Fig.1 shows the relationships between the part injured and the cause of death. As regards part injured, "chest" was the part in most cases. Including all part injured the chest, abdomen, neck and pelvis occupied more than 60% of all fatal injuries.

Fig.2 shows the relationships between the cause of death and what part of the worker was buried. As regards the buried portion, over 60% of workers who died were not buried entirely.

As far as the cause of death, suffocation accounted for 33%, pressure 22%, fractures 15% and rupture of internal organs 13%. 12% of deaths were due to injuries to the head including skull fractures and intracranial injuries.

The question then arises about the cause of suffocation. Suffocation is divides into three types:

① the worker could not breath because of pressure on their lungs.

② the worker could breath but there was little air in the collapsed soil. (lack of air)

③ both of the above occurred

It is difficult to distinguish them clearly. However, judging from the situation, we have divided them into two:

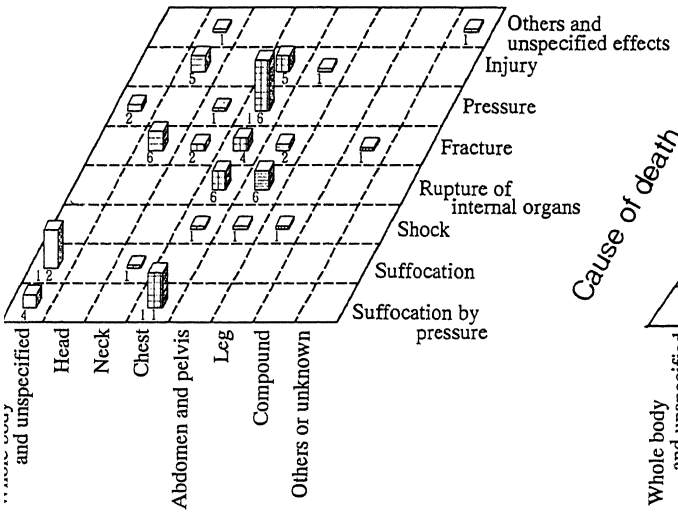


Fig.1 The relationships between the part injured and the cause of death

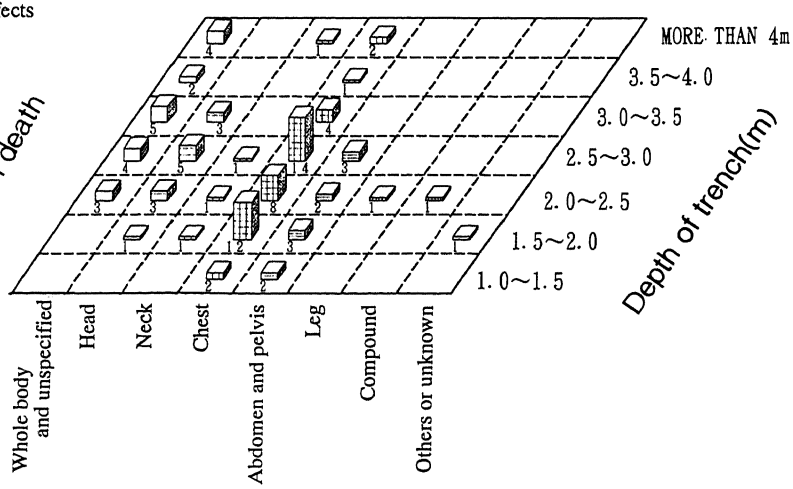


Fig.3 The relationships between the depth of the trench and what part of the worker was buried

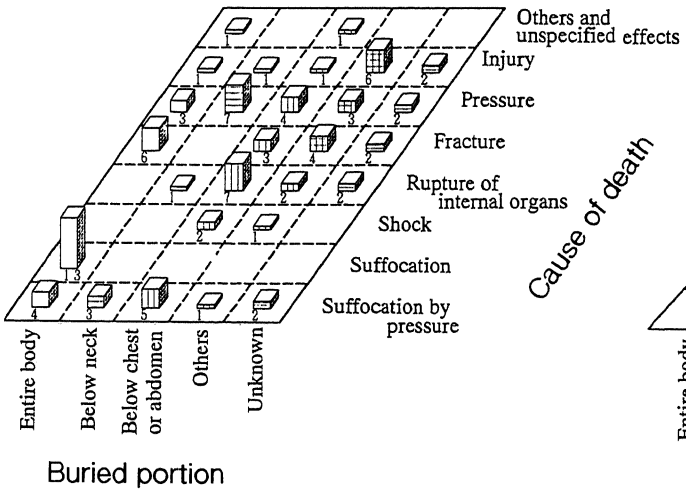


Fig.2 The relationships between the cause of death and what part of the worker was buried

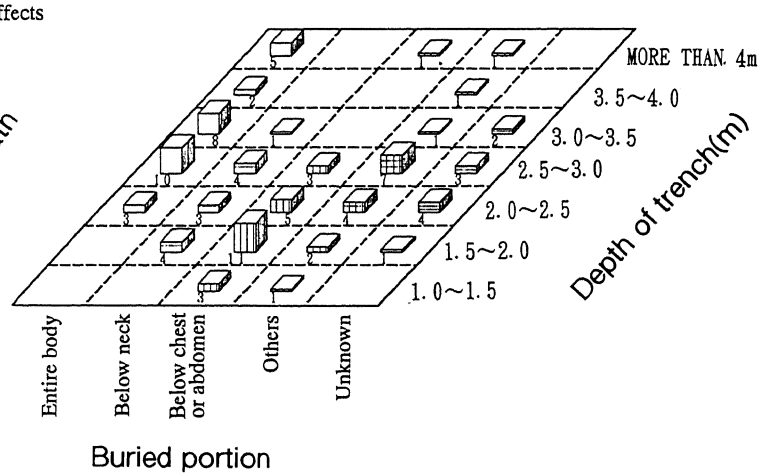
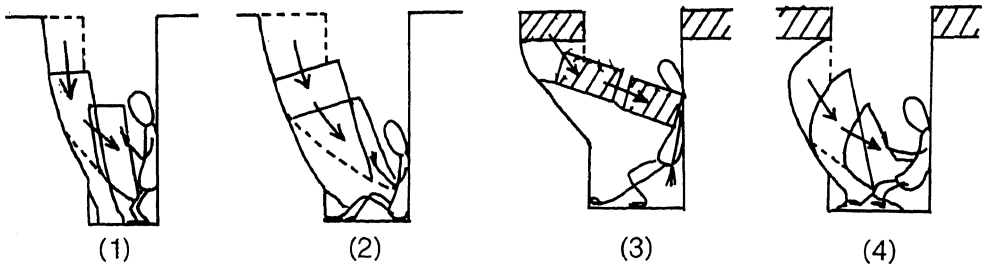
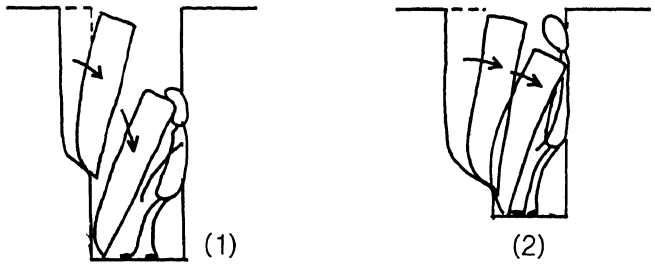


Fig.4 The relationships between the cause of death and depth of the trench

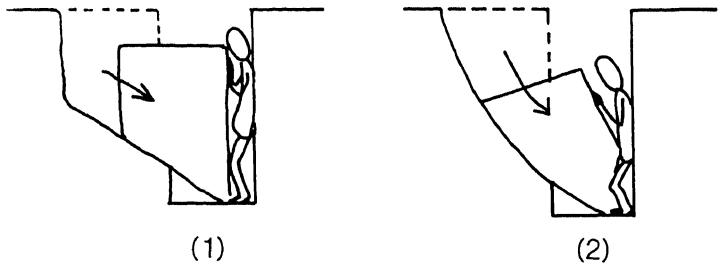
Type-1 Failure due to surface slip



Type-2 Failure by toppling



Type-3 Failure by sliding or rotation



Type-4 Failure by falls or block failure

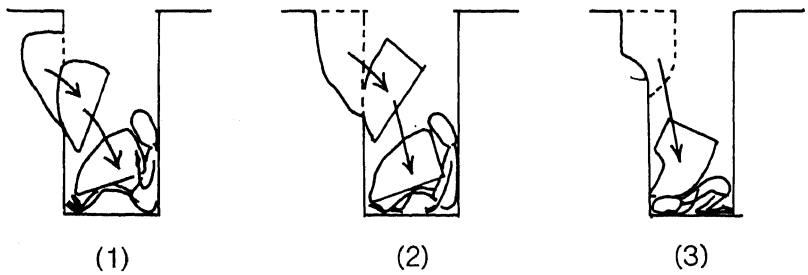


Fig.5 Classification of trench failures

the first (suffocation by pressure) belongs to No. ① the second (suffocation (the cause was unspecified)) belongs to No. ② or ③. From this view point, the second cause (suffocation (the cause was unspecified)) of suffocation only occupied 15%.

Fig.3 shows the relationships between the depth of the trench and what part of the worker was buried. Fig.4 shows the relationships between the cause of death and depth of the trench. These figures indicated that there was few workers who died buried entirely within 2.5m depth of trench. Over 90% of the worker that died experienced soil pressure on their chest or around them.

Almost all of the accidents due to suffocation were due to pressure on the workers' lungs. The other causes of death by the fracture, rupture of internal organs, and shock also come from the pressure of the collapsed earth. It is clear that even if the worker was not entirely buried, he would die because of the pressure of collapsed earth. The collapsed earth was concentrated on a part of the workers' body. That caused the most damage serious.

3-2 Classification of failures

As far as I know there has been no classification of trench failures that caused fatal accidents. In order to establish the failure prevention procedures, it is important to know what kind of failure caused the most serious damage to the worker.

It is difficult to categorise how the failure happened and how the collapsed soil caused the damage to the worker. Because of the condition of the failure was disturbed for the sake of the rescue. We examined the state of failures after the rescue and the testimonies of those who watched the accidents or rescued the buried worker.

This examination revealed the following characteristics of trench failure :

① Failure occurred as a clod or block of earth (harden soil sand or gravel). The clod or block of earth kept its shape until it hit the worker. This is one of reasons why the damage was so serious.

② The clod of earth kept moving until it reached the opposite wall of the trench. Therefore, even if the movement of clod of earth was small, the failure caused serious accidents.

③ Before the failure, cracks or fissures appeared. The cracks and fissures made failure easy to happen.

④ Almost of all the failures were in-slope failure. Toe failures were very few.

Looking at trench failures in detail, these were able to be divided into four types. Each type of failure is illustrated in Fig.5. It also indicates how the worker was injured in the trench.

3-2-1 Type-1 Failure due to surface slip (shear failure)

The soil mass slipped or fell along the slip surface. In this type, the lower part of trench wall consisted of relatively weak soil or sand. Since it called surface slip, the length of thickness of the failure soil was short.

Occasionally, the second and third failure occurred as shown Fig.5 Type-1. When the upper parts of the trench wall were consolidated by the traffic load etc., failure occurred due to the weight of upper part as shown in Fig.5 Type-1(3) and Photo.1.

3-2-2 Type-2 Failure by toppling

In this type, solid soil mass turned over as the wall or fence turned over as shown Photo.2. The clod of earth toppled and lean against the worker. The solid mass came apart from the surface along the cracks or fissures in the ground. These cracks or fissures occurred in the back-fill or the margin of back-fill and natural ground. The crack was observed in the remained trench wall beside the failure in Photo.3. The mechanism of the beginning of the failure was similar to Type-1.

3-2-3 Type-3 Failure by sliding or rotation (deep slide or slip)

In Type-3-1, the soil mass was bigger than in Type-1 or Type-2. The soil mass slides along the bedding surface as shown in Fig.5 Type-3 (1) and Photo.4. Almost of all cases the back-fill or weak line (basement of architecture, ditch or gutter) were located near the trench.

In Type-3-2, the soil mass was also bigger than in Type-1 or Type-2. It slipped along the circular arc surface when the ground consisted of cohesive soil as shown in Fig.5 Type-3 (2).

3-2-4 Type-4 Failure by falls or block failure

In this type, a clod or block of solid soil, sand or rock fell from the trench wall and hit the worker below. The mechanism of the beginning of failure was very similar to Type-1 and Type-2. This type of failure likely occurred by peeling when the gradient of trench wall was over 90 degrees (over hang).

Fig.6 shows the relationships between the type of failure and depth of the trench. It shows that even in a shallow trench, Type-1 and Type-2 failure caused serious damage.

3-3 Cause of failures

As far as trench excavations were concerned, over 80% of the fatal accidents were related to back-fill.(See Fig.7) In other words, fatal accidents occurred in man-made ground or where the soil had been disturbed due to earlier earthwork.

Back-fill is usually unconsolidated with discontinuities in the ground. Due to the excavation, the release of in-site horizontal stress led to the development of strain in the soil around the lower wall of the trench. At the first step of failure, a slip occurred in the lower part, and at the same time or just after it, the slip surface developed toward the ground surface. Cracks or fissures made failure easier to occur.

In addition to this, the back-fill behind the trench wall also caused failure. We examined some fatal accidents that occurred due to the back-fill behind the trench wall as shown in Photo.2.

51% of the accidents occurred at waterworks by the order of the city, town, village government. Almost of all waterworks usually executed along the streets so that there are a lot of buried things for example water pipes, electric lines, gas pipes and telephone lines. All clients, designers and contractors concerned with trenching work should notice this.

There are a few words to be said that other causes are given below.

① Disturbance by the weight and vibration of construction machines

② Weight and vibration of traffic load

③ Weight of pavement and weight of upper layers which had been consolidated by traffic load, etc.

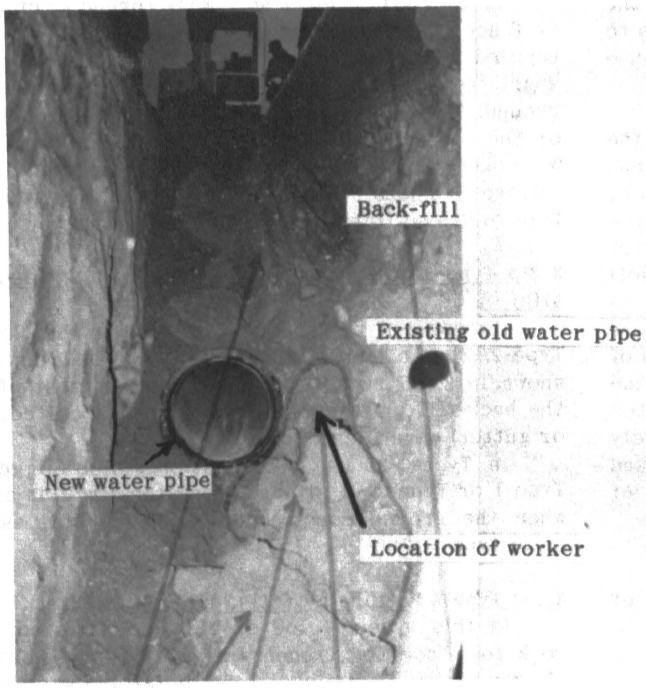


Photo.1 A fatalaccidents due to Type-1(4) failure in 2.6m depth of trench.

During setting new water pipe, the back-fill around the existing old water pipe collapsed.

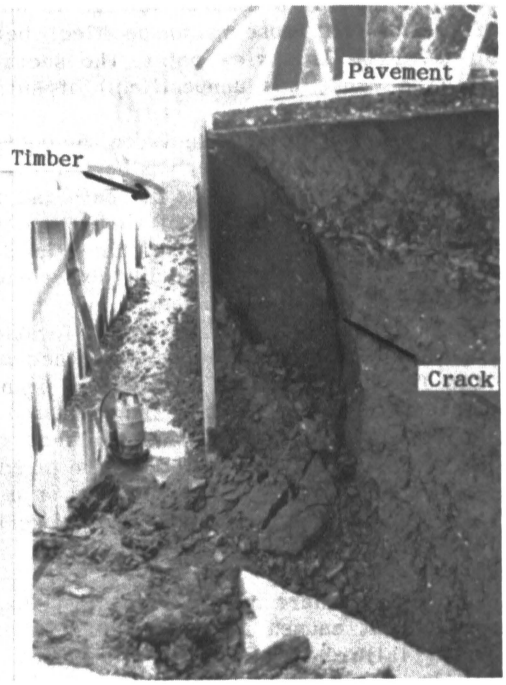


Photo.3 A fatal accidents due to Type-2 failure in 1.6m depth of trench.

There was the back-fill consisted of sand 0.5m behind the trench wall. Toppled clod of earth was observed.

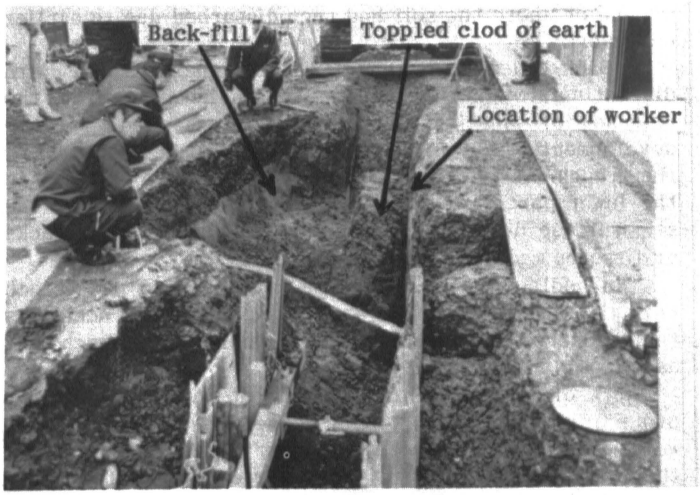


Photo.2 A fatal accidents due to Type-2 failure in 2.3m depth of trench.

There was a crack in the remained wall just beside the failure.

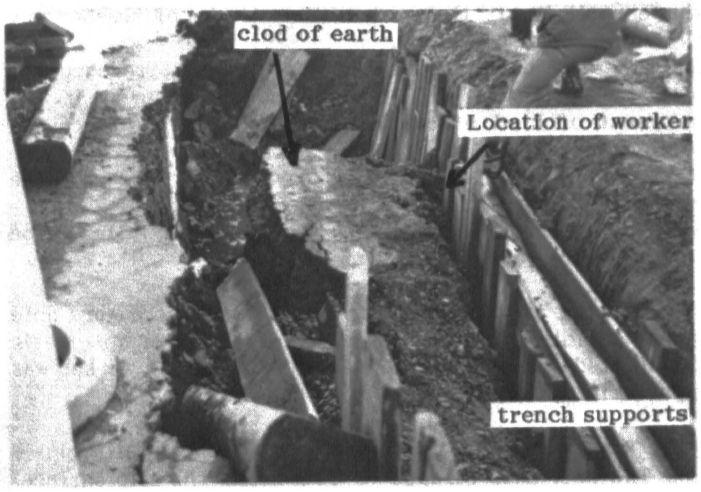


Photo.4 Afatal accidents due to Type-3(1) failure in 2.9m depth of trench.

The worker died between the insufficient trench supports. Saturated soil around the bottom was observed.

④ Ground water,rainfall, etc.

3-4 Size of trench and amount of failure

Fig.8 shows the relationships between the depth of the trench (vertical height) and amount of failure. Nearly 80% of the accidents involving small-scale trenches occurred when the height of the trenches was 3m or less. On the other hand, the amount of the failure spread widely in this diagram.

The degree of failure depends on the width of failure, with a large failure having a long length along the trench. This is the reason why even in a shallow trench a large clod of earth failure can easily occur.

The gradient of trench wall being more than 80 degrees amounted to 95%.

3-5 Execution of trench support

Fig.9 shows the situations of trench support. Fig.10 shows the kind of works the worker who died did when the fatal accident occurred. During the installation of trench support such as steel sheet pile retaining walls, 29% of the accidents occurred. Grading or leveling work in trenches without retaining structures proved to be dangerous for the workers who were in trenches.

The procedure of trench work such as waterworks, gas, electric line works may be classified as follows.

1) Digging by construction machines
2) Driving in steel sheets
3) Putting in trench supports
4) Installing of equipment (to lay pipes)
5) Dismantling strutting structures
6) Backfilling

In these type of work, the 3rd and 5th type of works are dangerous for workers. Because to carry out trench strutting, the worker should do it in the trench. During dismantling of the strutting, same danger exists. It means that there is a need of developing safety procedures for trench works.

4 CONCLUSION

We carried out a statistical analysis of various factors obtained from fatal accident data. This examination revealed the following characteristics of the fatal accidents due to trench failure :

1) As far as the cause of death, suffocation accounted for 32%, pressure 21%, fractures 18% and the rupture of internal organs 13%. In each case, each worker who died experienced soil pressure on their chest or abdomen. The collapsed earth was concentrated on one part of the workers' body. That caused the most damage serious.

2) As regards the buried portion, about 60% of the workers who died were not entirely buried. The percentage of the workers who were buried entirely accounted for 31%.

3) Trench failures were able to be divided into four types. Each type of failure is

1-) Type-1 Failure due to surface slip
2-) Type-2 Failure by toppling
3-) Type-3 Failure by sliding or rotation
4-) Type-4 Failure by falls or block failure

4) Failure occurred as a clod or block of earth. The clod or block of earth kept its shape until it hit the worker. Because of the narrow space in trench, the worker could not escape, and the worker was trapped between the clod of earth and the trench wall.

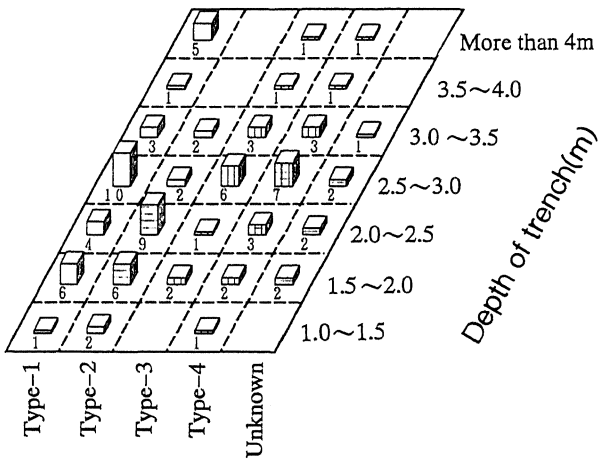


Fig.6 The relationships between the type of failure and depth of the trench

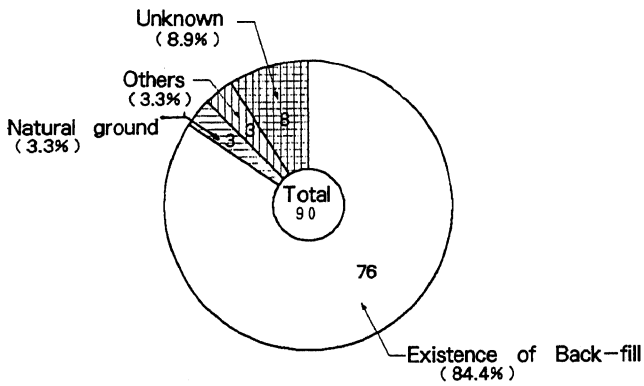


Fig.7 Existance of back-fill

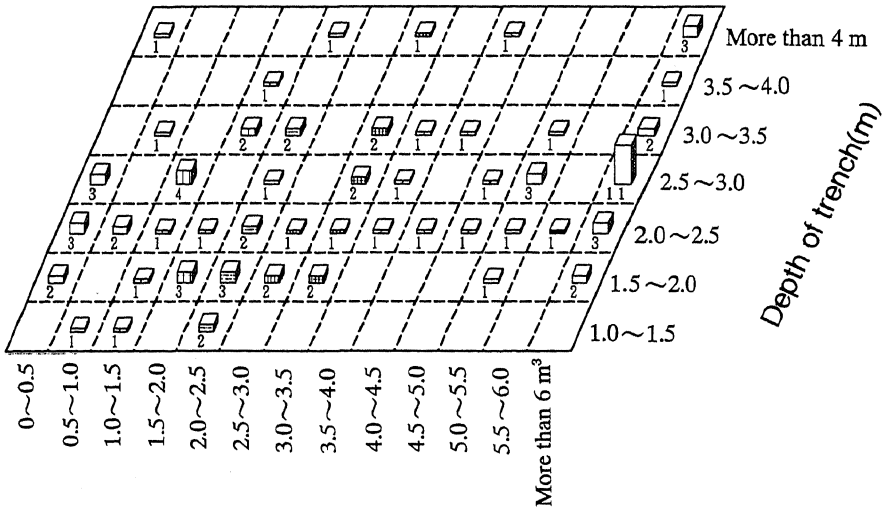


Fig.8 The relationships between the depth of the trench and amount of failure

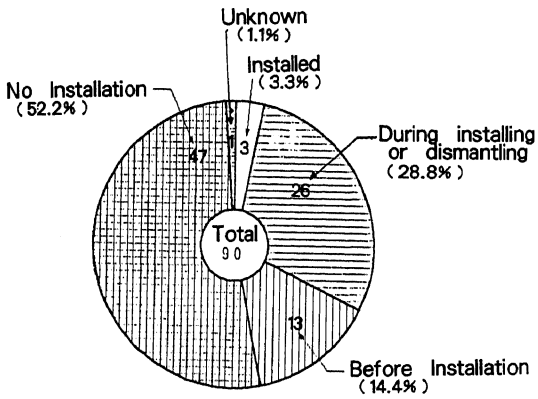


Fig.9 Situations of installing earth support

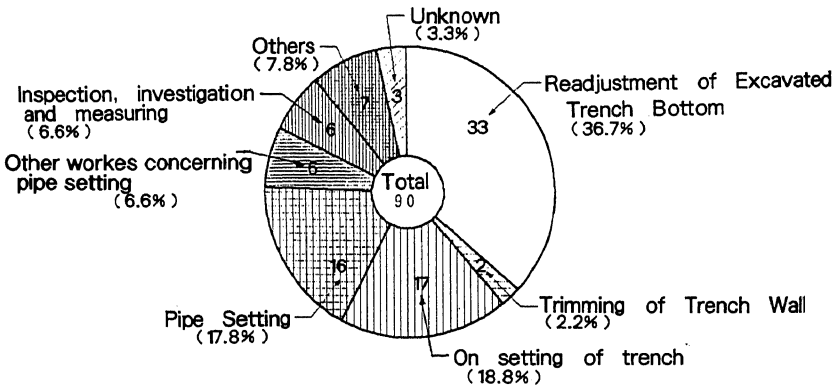


Fig.10 Classification of works

5) 84% of the fatal accidents were related to back-fill. In other words, fatal accidents occurred where the soil had been disturbed due to earlier earthwork.

6) Nearly 80% of the accidents involving small-scale trenches occurred when the height of the trenches was 3m or less. 23% of the accidents happened in trenches of less than 2m depth.

7) Nearly 30% of the workers died during installing and dismantling trench supports. A safety procedure of installing and dismantling trench supports that dose not require workers to be in the trench needs to be developed.

Designers, Constructors and Government related to trench work should understand that the danger of failures exist even in a shallow trench. The development o effective trench support systems for each failure type an safety procedures are highly expected.

REFERENCE

Toyosawa, Y., Horii, N and Tamate, S (1992), " Centrifug model tests of trench failures by using excavation simulation system", Proceedings of the 47th annua conference of the Japan Society of Civil Engineers, Volum 3, No. 818 - 819 (in Japanese).